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Preferential policies promote municipal solid waste (MSW) to energy in China: Current status and prospects

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A B S T R A C T

As the largest developing country in the world, China creates a considerable quantity of municipal solid waste (MSW), which is one of the most serious urban pollution sources. Not only can MSW to energy contribute to a significant reduction in greenhouse gas (GHG) emissions caused by landfills, but it can also generate clean energy to offset the increasing energy requirements. MSW to energy is a novel eco-friendly renewable energy resource and has attracted the attention of both national and local governments with various preferential policies. China's MSW to energy development has the characteristics of late starting, large scale and rapid growth, so it urgently needs to present how these policies exert influence on the prosperity of MSW to energy in view of latest situations. This paper initially illustrates the current status of MSW management in China. The application of landfill gas-fired and MSW incineration power generation is then analysed in detail. Meanwhile, the present situation of clean development mechanism (CDM) projects in MSW to energy is presented. In addition, a series of preferential policies and regulations to encourage the expansion of MSW to energy, especially MSW incineration, are offered. Finally, the market potential of MSW incineration power generation is analysed and reasonable suggestions are proposed. Owing to the demand for sustainable development, MSW incineration power generation is capable of significant growth and has tremendous market potential for investors in future decades with the support of the Chinese government.

Contents

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1. Introduction

The continued development of the global economy and the consistent improvement of people's living standards are producing a large quantity of municipal solid waste (MSW). MSW, which refers to the materials discarded in urban areas (including predominantly household waste with added commercial waste) and collected and disposed by municipalities, has long posed threats to environmental quality and human health [1]. MSW can, however, be converted into a renewable energy resource to the extent that the energy content of the MSW source stream is biogenic. In a pattern of sustainable development, a MSW to energy plan acquires energy from waste either through direct combustion (e.g., incineration, pyrolysis, and gasification) or biochemical conversion.

Although MSW increasing is a problematic issue throughout the world, it is more severe in China owing to its rapid urbanisation and industrialisation. The total MSW amount increased from 31.3 million tonnes in 1980 [2] to 179.36 million tonnes in 2011 China [3], and will increase to 480 million tonnes in 2030 [4,5]. No other country has ever experienced as large and as fast an increase in solid waste quantities that China is now facing [2,6]. It is commonly accepted that the unprecedented increase of MSW has become another major urban problem in China along with energy shortages and traffic congestion and that nearly two-thirds of China's cities are being afflicted with chronic “waste siege” phenomenon [7]. It is imperative to control the ever-increasing MSW. Fortunately, the Chinese government has made great efforts and tremendous progress on tackling these problems. In 2011, the disposal rate of MSW had reached 91.9% and harmless disposal rate had reached 79.7% in Chinese cities [3].

The staggering development of Chinese economy is accompanied by severe pollution of the ecosystem due to its extensive economic growth model. China, the energy matrix of which is coal-dominated, reaching an annual gross domestic product (GDP) growth of 9.2%, alone accounted for 71% of the global energy consumption growth in 2011 [8]. The consumption of standard coal, reaching 3.25 billion tonnes, grew by 11.2% in 2010 thus surpassing the US and becoming the world's largest energy consumer by using 20.3% of global energy [9–11]. At the same time, the energy import were 557.36 million tonnes standard coals and export 88.46 million tonnes in 2010, while the counterparts were 269.52 million tonnes and 114.48 million tonnes in 2005, demonstrating China having become an absolute energy importer [12]. However, coal consumption has been the main cause of greenhouse gas emissions, accounting for 82% of China's emissions in 2006 [13]. Then, China ranked first in carbon dioxide emission in the world, surpassing the US in 2007 with approximately 8% more emissions [9,14]. As the world's largest MSW generator, energy consumer and carbon dioxide emitter, China has explored transitional development and put developing low carbon economy as its primary task [15–17]. Increasing the proportion of renewable energy is the only way to create a sustainable energy infrastructure. MSW to energy, as a novel renewable energy resource, could address the problems of landfill environmental pollution, reduce GHG emissions, and meet an increasing energy demand caused by economic growth. Although there are still a host of difficulties to promote this novel industry, such as poor combustion performance due to the high moisture content and low calorific value of Chinese MSW, secondary contamination, and imperfection of some standards, the Chinese government has attached more attention on it in terms of various favourable policies and more stringent standards.

So far, several previous studies have reviewed the status of MSW to energy in China, in terms of technology developments and pollutant emission control, etc. [2,6,18–21] and some papers have focused on the renewable energy policy system in China [11,12,22–25]. However, there is little systematic research and review concerning on how Chinese preferential policies are exerting influence on the prosperity of MSW to energy. China's MSW to energy development has the characteristics of late starting, large scale and rapid growth, so it urgently needs to research the policy system of MSW to energy in view of the latest situations, based on a new round of preferential policies, to promote the development of MSW to energy further [23]. In addition, the Chinese government has provided strong support for civil and international capital investment in this industry. Owing to the obvious environmental benefits and the vigorous support of the government, MSW to energy in China is poised to enter a stage of rapid development while providing great opportunities to investors. The objectives of this paper are to present an updated review and provide innovative information on MSW to energy in China. First, MSW generation and its management status in China are introduced. Second, applications of landfill gas-fired power generation and MSW incineration, including clean development mechanism (CDM) of MSW to energy, are illustrated. Additionally, the various favourable policies of MSW incineration are introduced, and the market potential of MSW incineration in China is analysed. Finally, prospects and proposals are summarised.

2. MSW generation and management status in China

The sustained growth of the Chinese economy, with its rapid urbanisation and improved living standards, has generated a large amount of MSW and a significant rise in total energy consumption. Fig. 1 shows the urbanisation trend of China over the past three decades [26]. It can be observed that the urban population of China in 2011 has reached 691 million, with an urbanisation rate of 51.27%—2.86 times that of 1978. This means that the Chinese urbanisation rate is gradually closing on the average level in mid-income countries. Because of the accelerated urbanisation in China, its growth rate of MSW generation ranks first in the world and its total amount ranks at the forefront of high-yielding countries. The total amount of MSW reached 179.36 million tonnes in 2011 and is still increasing at the rate of 8–10% each year [21,27,28]. It is estimated that the annual amount of MSW will reach 260 million, 323 million and 480 million tonnes in years 2015, 2020 and 2030, respectively [4,29]. At present, the daily amount of MSW per capita in urban areas is 1.12 kg and the annual growth rate of MSW generation is 15–20% in cities with more fluctuating populations such as Shanghai, Beijing and Wuhan. The

Nomenclature

MSW	municipal solid waste
GHG	greenhouse gas
CDM	clean development mechanism
LFG	landfill gas
CER	certified emission reduction
UNFCCC	United Nations Framework Convention on Climate Change
NDRC	National Development and Reform Commission
NPC	National People's Congress
BOT	build operate transfer
GDP	gross domestic product
GNP	gross national product
VAT	value added tax

shortage of harmless MSW disposal capabilities grows year by year. In 2011, the MSW collected in China was 164 million tonnes (an increase of only 20.1% from 2002), representing a compound annual collection growth rate of only 2.06%, far lower than the waste yield growth rate during the same period. By the end of November 2011, the accumulated amount of untreated MSW reached 8 billion tonnes, occupying 53,333 square kilometres of land. Of more than 600 cities in China, there are some 400 large and medium cities that have already been caught under the surroundings of waste, and a quarter of these cities have no proper location for a landfill [27]. The grim situation of this prominent “waste siege” phenomenon has already caused serious pollution to surface water, underground water and soils, destroying the ecological environment [30]. Therefore, MSW management, because it is closely related to the environment and people's livelihood, has become an issue of great concern to the Chinese government.

MSW management is a systematic project that includes collection, transportation, transferring, treating and recycling. Chinese MSW management began in the late 1980s; prior to the adoption of this management, MSW was placed in open dumps. While the disposal rate of MSW was less than 2% before 1990, the level of MSW disposal was gradually improved in the 1990s. By 1999, there were 696 MSW disposal plants with the disposal rate of 63.4%, and less than 200 harmless treatment plants with a harmless treatment rate of 20.3% in 668 Chinese cities [27]. Fig. 2 shows the situation of MSW management in China from 2002 to 2011 [31,32]. It can be clearly observed that the MSW management industry in China has been under continuous development during the past decade. By the end of 2011, the number of harmless treatment plants of MSWs had increased to 677 and the treatment rate had reached 79.7%—3.93 times than that of 1999 [31]. The development of the MSW management industry grows continuously with further support from national environmental investments: the investment in the MSW management industry will reach US$ 115 billion annually during the “12th Five-Year” period (2011–2015) and US$ 150 billion during the “13th Five-Year” period (2016–2020) [33]. Apart from drawing on advanced experiences from developed countries, the Chinese government has taken some other measures with Chinese characteristics to promote the development of MSW disposal. For example, each city in China wants to acquire the title of “environmental protection model cities” or “eco-cities”, however, one of the standards for obtaining these titles is MSW safe disposal rates must be at least 85% and 90%. Therefore, waste minimisation and safe disposal are usually included in action plans of these cities, having positive influence on MSW disposal industry. Model cities can provide an example of success to other cities that attempt to improve their MSW management practices, forming a sustainable development mode [17]. For example, Guangzhou, once being afflicted with “waste surrounding” due to high population density, achieved negative growth of MSW disposal amount historically in 2012, which represented the great progress on MSW management [34]. Furthermore, Conghua circular economy industry zone will be constructed with the investment of US$ 126 million to boost the development of MSW management [35]. Guangzhou, as well as other parts in China, is on its way to become cleaner and tidier.

With the 3R principle of volume and mass reduction, resource reuse and recycle in mind, landfill, composting and incineration are the three primary MSW disposal methods [6,7]. Landfill is cost effective and easy to implement; however, it may lead to secondary pollution problems such as water and air pollution and soil

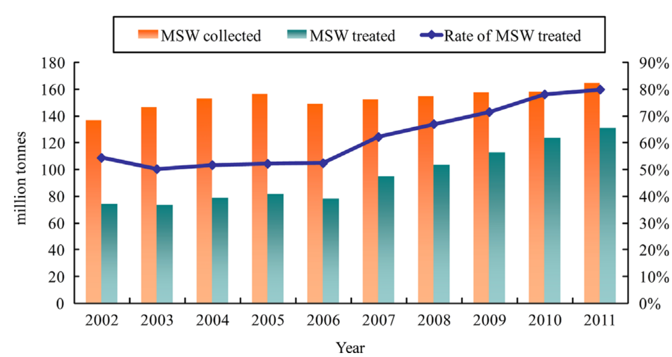


Fig. 2. The situation of MSW management in China from 2002 to 2011. Refs. [31,32].

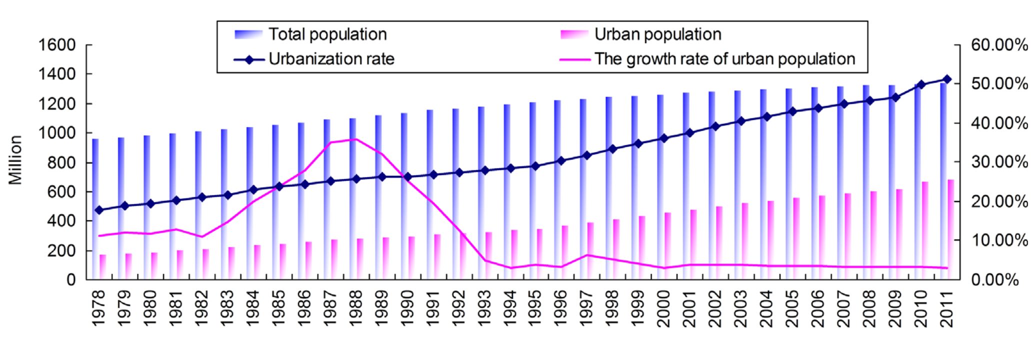


Fig. 1. The urbanisation trend of China over the past three decades. Ref. [26].

Table 1
The status of MSW disposal in China from 2003 to 2011.
Source: Refs. [31,32,36–39].

Year	Treatment capacity (tonnes/day)				Number of facilities for treatment			
	Sanitary landfill	Composting	Incineration	Total	Sanitary landfill	Composting	Incineration	Total
2003	187,092	16,511	15,000	219,607	457	70	47	575
2004	205,889	15,347	16,907	238,519	444	61	54	559
2005	211,085	11,767	33,010	256,312	356	46	67	471
2006	206,626	9506	39,966	258,048	324	20	69	419
2007	215,179	7890	44,682	271,791	366	17	66	460
2008	253,268	5386	51,606	315,153	407	14	74	509
2009	273,498	6979	71,253	356,130	447	16	93	567
2010	289,957	5480	84,940	387,607	498	11	104	628
2011	300,195	–	94,114	409,119	547	–	109	677

contamination. Composting, costly to implement and maintain, has become an unpopular method. Furthermore, the fertiliser, being of low nutrient contents and containing certain heavy metals, can only be used as a soil modifier. Although incineration requires significant capital for investment, operation and maintenance, it has become the prevalent MSW disposal method; it occupies less land, substantially reduces the volume and mass of MSW and requires minimal pre-processing. More importantly, heat from the combustion can be used as an energy source for the generation of steam and electricity. Table 1 shows the status of MSW disposal in China from 2003 to 2011 [31,32,36–39]; the development trend of MSW disposal in China shows that the capability of landfill disposal has steadily risen while composting has reduced year by year. As for incineration, the disposal capacity dramatically increased (tenfold over ten years) and is still undergoing staggering growth. In 2011, landfill disposal capacity accounted for 61.4% of the total amount (higher than the average level of 45.9% in developed countries), while incineration was of 15.84% (much lower than the average rate of 39.9% in developed countries). Moreover, there is almost no MSW recycling in China. Evidently, we can conclude that China falls significantly behind developed countries in MSW disposal technologies [40]. The arable land per capita in China is not more than 1.333 m^2, which is less than 1/2 of the global average, as well as 1/17th of that in Canada and 1/8th of the United States [41]. With a finite land capacity for a sustainable development, the landfill is the last alternative that should be considered in China; clearly, there must be comprehensive utilisation of other treatment methods. MSW incineration power generation, which has been widely used in developed countries, is the most effective method to solve the current problems. For example, the ratio of MSW incineration is 91% in Singapore and 85% in Japan [42,43]. In Germany, all landfill sites were shut down in 2005; just one of the incineration plants owned by the Cleaning Company in Germany can incinerate 520,000 tonnes of MSW and generates 188 million kWh of electricity annually. The energy, together with 77 million kWh generated from landfill gas-fired facilities, is sufficient to meet the electricity consumption of German 100,000 households [44]. Additionally, incineration can curb GHG emissions generated by landfills and offset emissions from fossil fuel power plants—dual emission reduction benefits. Thus, the Chinese government is vigorously encouraging MSW incineration as a preferred alternative.

With this enormous focus and determination in managing environmental pollution, a low carbon economy is now regarded as the core of future economic development in China. MSW management, closely related to people's lives and health in the process of urbanisation, has already become a key factor in the low carbon economy. Therefore, more importance has been and will be attached to MSW management from the national and local governments in China.

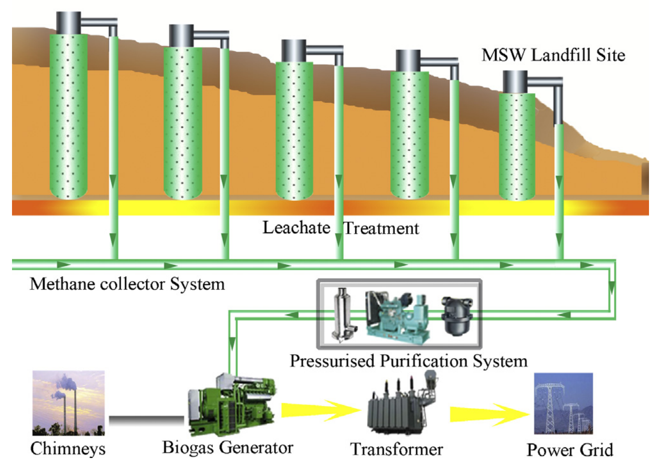


Fig. 3. The process of landfill gas-fired power generation.

3. Application practice of MSW to energy in China

MSW to energy means acquiring energy from waste either through direct combustion (e.g., gasification, incineration, and pyrolysis) or biochemical conversion. Since MSW incineration and landfill gas-fired power generation are the two primary MSW to energy technologies successfully applied in China, we give priority to analyse application practice of these two methods at length.

3.1. MSW to energy mode

3.1.1. Landfill gas-fired power generation

Landfill gas (LFG) is a type of gas emitted from the fermentation of large amounts of organic waste in underground landfills. Containing 45–65% methane, 25–35% of carbon dioxide, and 10–20% of trace elements such as nitrogen and oxygen, the LFG is a renewable energy resource with a calorific value half that of natural gas. As the main content of LFG, methane has a potent effect on global warming; its contribution to the greenhouse effect is twenty-one times that of carbon dioxide. It has been determined that approximately 3–4% of all global anthropogenic GHG emissions come from LFG. Landfill gas-fired power generation can turn methane into carbon dioxide, which has lower greenhouse effect,

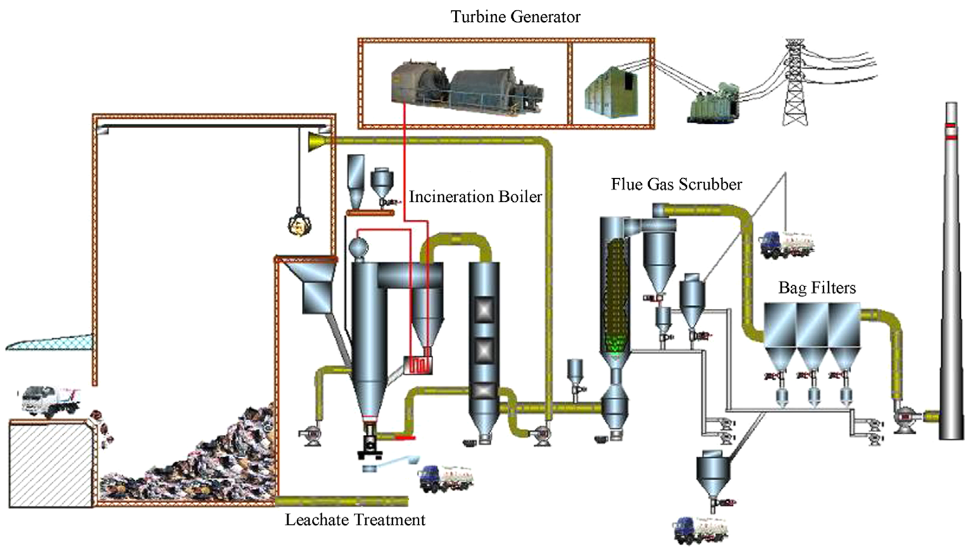


Fig. 4. The process of MSW incineration power generation. Ref. [47].

Table 2
MSW characteristics in China.
Source: Ref. [48].

Moisture content (%)	Low calorific value (kJ/kg)	Organic ingredients (%)	Recycle ingredients (%)
45–65	3000–5000	40–60	10–25

Table 3
The comparison of different MSW incinerators in China (to the end of 2012).
Source: Refs. [32,49].

Incineration type	Number of incinerators		Total incineration capacity (thousand tonnes/day)		Total power generation capacity (MW)	
	2011	2012	2011	2012	2011	2012
Stoke grate	61	77	54	71	943	1250
Fluidized bed	53	59	45	50	1140	1300
Pyrolysis + rotary kiln	6	6	3	33	47	50
Total	120	142	102	154	2130	2600

and can mitigate the role of global warming [45]. The process of landfill gas-fired power generation is illustrated in Fig. 3. The LFG is first collected through a methane collector system and then purified through a pressurised purification system. It is subsequently placed into a biogas generator to generate electricity through combustion. The exhaust gas generated by the gas engine is emitted through exhaust pipes, heat exchange devices, silencers, and chimneys [46].

3.1.2. MSW incineration

A MSW incineration power system generates electricity by driving turbines with high temperature steam produced by the incineration of MSW, as shown in Fig. 4 [47]. After transporting by closed trucks, MSWs were poured into a storage pool to ferment for approximately three days. The characteristics of MSW in China are unsorted coupled with low calorific values and high moisture rates, as shown in Table 2 [48]. This ferment procedure could reduce the materials' humidity and increase their heat values. MSWs were then burned in incineration boilers to heat water to generate steam, which is the driving force of turbine generators. The flue gases and solid residues generated during the MSW incineration process should be treated accordingly to avoid secondary environmental pollution, especially the flue gases which contain significant amounts of dioxins, particulate matters, heavy metals, sulphur dioxide, and hydrochloric acid. The flue gases are first sent into a flue gas scrubber to remove acidic material, after which bag filters are used to remove dust particles so that the gas can meet the final emission standards. Fly ash, one of the flue gas residues, is a hazardous substance and should be dealt with in accordance with hazardous material waste laws.

The incinerator, which accounts for approximately 50% of the MSW incineration power plant costs, is the core of MSW incineration process. The technologies of its craft and design have a direct influence on MSW disposal effects and economic benefits, as well as a direct impact on the subsequent treatment of flue gases. There are various incinerators such as stoke grate incinerators, fluidised bed incinerators, rotary kiln furnaces and pyrolysis gasification furnaces. Table 3 shows the comparison of different MSW incinerators in China [32,49]. As shown in Table 3, stoke grate incinerators and fluidised bed incinerators predominate, while pyrolysis furnaces and rotary kiln furnaces are only adopted on a small scale. At present, most incineration facilities adopting mechanical stoke grate technologies are located in the more economically developed cities of eastern coastal areas, especially in the provincial capital and the sub-provincial cities. By contrast, incineration facilities utilising fluidised bed technologies are predominantly located in small and medium cities, as well as the large cities in the middle and western regions of China that are economically less developed. It is for the reason that the cost of investment and operation of fluidised beds are comparatively low, and coal, as the auxiliary fuel for fluidised beds, is abundant in central and western China. The facility costs for stoke grate incinerators vary between US$ 98 million and US$ 164 million thousand tonnes daily of treatment capacity. In comparison, the costs for fluidised beds are merely half of that. The operation and maintenance (personnel training, fuel, parts repair and replacement) of stoke grate incinerators are also costly, varying between US$ 16 and US$ 32 per tonne MSW treated, while it is approximate US$ 10–US$ 20 for fluidised beds [50]. It must also be pointed out that the market share of stoke grate becomes increasingly higher than that of the fluidised bed. The increasing rates of the number, total incineration capacity and total power generation capacity of stoke grate incinerator are 26.2%, 31.5% and 32.6% respectively from 2011 to 2012, while counterparts of fluidised bed incinerator are 11.3%, 11.1% and 14.0% respectively. The reason for this

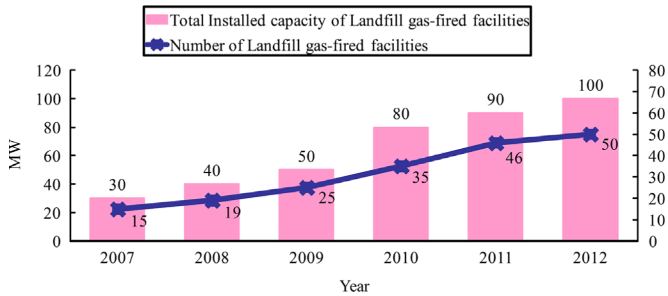


Fig. 5. The total installed capacity and the number of landfill gas-fired power generation facilities in China from 2007 to 2012. Refs. [36–39,49].

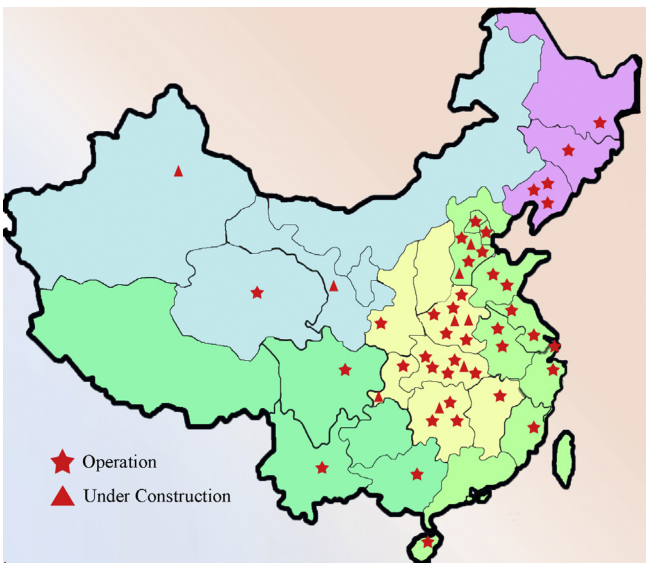


Fig. 6. Distribution of landfill gas-fired power generation facilities in China.

tendency is that the technology of fluidised bed is not as mature and stable as stoke grate; therefore, all advantages, such as complete combustion of native MSW through mixed unsorted collection, less dioxin emission, and no additional investment in sewage treatment etc., are not as good as expected. Due to this reason, the Chinese government is prone to support promotion of stoke grate at present, which is best illustrated by the first selection of "3A Selection of MSW Incineration plants" in China lasting a whole year from March, 2012 to March, 2013. All of the MSW incineration plants adopting fluidised bed technology were unconditionally excluded for the selection, which represented the government's attitude and hindered the development of fluidised bed technology to a certain extent [51].

3.2. The development of MSW to energy

Because of funding and technology constraints, China fell behind the developed countries in the MSW to energy process; its first MSW to energy facility was not placed in operation until 1988 [52]. MSW to energy has been encouraged since the "10th Five-Year Plan" period (2001–2005), after which MSW to energy has undergone rapid development to benefit both the economy and the environment. Before 2007, the Chinese government subsidised landfill gas-fired power generation through preferential policies and increased funding. However, because of the rapid urbanisation and increasing population density occurring in large and medium Chinese cities, there are no suitable locations to build sanitary landfill sites to establish landfill gas-fired facilities. Therefore, China is concentrating on transforming existing landfill sites

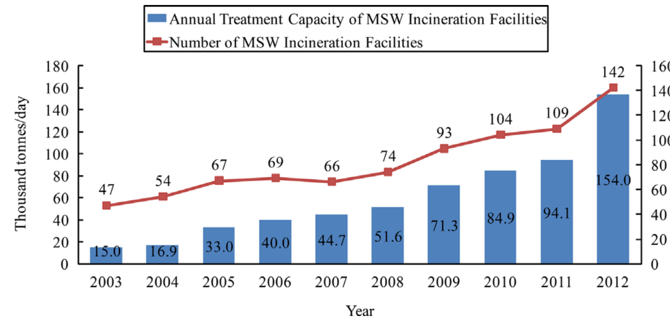


Fig. 7. The daily processing capacity and the number of MSW incineration facilities in China from 2003 to 2012. Refs. [3,55–62].

(already filled or still in operation) to generate power in large and medium cities and building sanitary landfill sites in areas that are comparatively abundant in land resources. Since 2007, the Chinese government has subsidised MSW incineration to take advantages of less area occupation, considerable volume reduction (approximately 90%), substantial mass reduction (approximately 70%) and complete disinfection [53]. This strategy is suitable for large and medium cities, especially for the economically developed cities that are the primary source of MSW.

3.2.1. Landfill gas-fired power generation

The utilisation of landfill gas-fired power generation in China started relatively late compared to developed countries. Until 1998, China cooperated with the Asia Huimin Environmental Group of the United States to establish its first landfill gas-fired power facility at the Tianziling MSW landfill plant in Hangzhou, with a generation capacity of up to 16 million kWh of electricity annually [54]. Fig. 5 shows the situation of landfill gas-fired facilities from 2007 to 2012 [36–39,49]. It can be seen that both the total installed capacity and the number of plants steadily increased by two times. The distribution of landfill gas-fired power facilities in China at the end of 2012 is depicted in Fig. 6, showing that the facilities currently in operation are primarily built in central and eastern regions with the amount of approximate 50 and an installed capacity of 100 MW [49], while most of the facilities under construction are distributed in central regions, a few in western regions and none in eastern regions due to a lack of land resources. For the sake of power generation, the landfill site must have a certain scale and storage capacity. However, for developed cities with dense population in east China, the lack of land resources for landfills has become a predominant issue. Thus, landfill plants must be built far from urban areas, which will increase the costs and environmental pollution caused by transportation. In recent years, the Chinese government has turned to support MSW incineration partially owing to these limitations. Therefore, the development of landfill gas-fired power generation will level off in the near future as large scale construction becomes almost impossible.

3.2.2. MSW incineration

Although MSW incineration power generation in China is a recent development, the MSW incineration power generation technologies have undergone rapid development with the demand for a low carbon economy and the encouragement of national policies. Since the inception of the first incineration power plant in 1988, the daily MSW incineration capacity of a single plant has doubled ten times [52]. Fig. 7 shows the daily processing capacity and the number of MSW incineration plants from 2003 to 2012 [3,55–62]. By the end of 2012, there were 142 MSW incineration power plants in operation—three times than the 47 plants in 2003

Table 4
MSW incineration power plants of significance in China.
Source: related news

Year	Incineration capacity (tonnes/day)	Name	Installed capacity (MW)	Electricity parallel to grid (million kWh)	Type of incinerator
1988	300	Shenzhen Qingshui River MSW incineration plant	2 × 0.5	–	Stoke grate
2002	1000	Shanghai Pudong MSW incineration plant	2 × 8.5	100	Stoke grate
2011	2000	Shandong Jinan second MSW incineration plant	2 × 18	270	Stoke grate
2013	3000	Beijing Lujiashan MSW incineration plant	2 × 30	310	Stoke grate

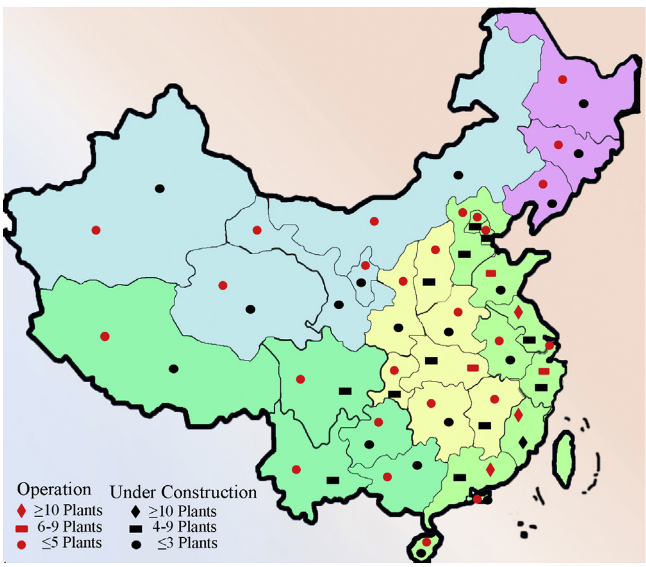


Fig. 8. Distribution of MSW incineration facilities in China.

—with a total installed capacity of more than 2600 MW [31,32]. Some significant MSW incineration power plants are shown in Table 4. In 2013, the Lujiashan incineration plant (Asia's largest MSW incineration power generation project) will undergo a trial operation and eventually supply 320 million kWh of electricity to the grid per year, which is equivalent to the electricity generated from 0.14 million tonnes of standard coal [63]. The distribution of MSW incineration facilities operating and under construction is shown in Fig. 8. More than 2/3 of the incineration power plants are concentrated in the Yangtze and Pearl River Delta regions in eastern coastal areas; the rest are located in the middle and western provincial capital cities. Obviously, we can conclude that MSW incineration facilities currently operating in China are primarily located in cities that are economically developed and densely populated.

More important, it also should be noted from Fig. 7, the total MSW incineration capacity was 154 thousand tonnes per day in 2012, over ten times than the 15 thousand tonnes in 2003, while the number of incineration plants increased by two times at the same time. The statistics illustrated that newly built incineration facilities tend to be large scale, with MSW incineration capacities generally greater than 600 tonnes per day. In large and medium cities, the capacity could be as high as 2000–3000 tonnes, or even 5000 tonnes per day. This is because MSW incineration power generation project sites are difficult to find, and the plant will most likely be constructed in large scale once a site was found. In addition, because MSW incineration requires massive funding and complex technologies, scale economy could ensure enterprises to obtain better economic benefits [64]. More importantly, a larger scale MSW incineration tends to use more advanced technologies and will ultimately be better for the environment. Therefore, the Chinese government is vigorously promoting the construction of large incineration plants. At present, there are approximately 75 MSW incineration power plants under construction with the potential MSW incineration capacity of up to 110,000 tonnes per day and an installed capacity more than 2200 MW. These newly added MSW capacities would exceed those of all MSW incineration power plants currently in operation. From Fig. 8, it can be observed that the distribution of the MSW incineration plants under construction is extremely different from that of the MSW incineration plants already in operation. Apart from the eastern regions, the number of plants in the central and southern regions is also greatly high, and even higher than that in some of the eastern provinces. Yunnan province, which is famous for its tourism industry, has developed its incineration power generation with great effort. There are twelve incineration power plants that will be built before 2015; together with their four existing plants, they will incinerate 4.169 million tonnes of MSW, approaching 62% of the predicted MSW, and possess an installed capacity of 286.5 MW per year. By 2020, another seven incineration plants will be built [65]. Most provinces in China are active in building incineration plants (except for the economically underdeveloped areas to the northwest and northeast). China will add another 384 MSW incineration power plants by the year 2015, with an incineration capacity of up to 0.31 million tonnes of MSW per day [66].

3.3. MSW to energy and clean development mechanism (CDM)

The clean development mechanism (CDM) is a new international cooperation mechanism, with its core content focussing on helping developing countries that undertake GHG emission reduction projects with funds, advanced technologies and equipment provided by developed countries. The certified emission reductions (CERs) issued for these projects can be counted towards the emission reduction goals for developed countries observing the "Kyoto Protocol" [67].

The rapid development of the global CDM market has vigorously advanced the low carbon economy in developing countries. Since the formation of the CDM market, more than 80% of the global CDM market share has been dominated by China, India, Brazil, and South Korea. Through the contributions of significant GHG emission reductions combined with the guidance and support of the government, the CDM market in China has prospered, steadily ranking first in the world ever since formally joining the CDM market in 2005. According to statistics from the United Nations Framework Convention on Climate Change (UNFCCC), as of January 31, 2013 there were 3206 CDM projects registered in China accounting for 52.9% of the global CDM projects. It is estimated that the annual CERs for global CDM projects are approximately 79 million tonnes CO_2e, with 51 million tonnes CO_2e expected to be in China, accounting for 64.7% of the global total amount. There were 2076 CDM project activities that

Table 5
Statistics of MSW-to-energy CDM projects registered by the NDRC and the UNFCCC.

Year	Registered by the NDRC[a]				Registered by the UNFCCC[b]			
	Landfill gas-fired		Incineration		Landfill gas-fired		Incineration	
	Number	Estimated CERs (tCO_2)	Number	Estimated CERs (tCO_2)	Number	Estimated CERs (tCO_2)	Number	Estimated CERs (tCO_2)
2005	3	633,032	0	0	1	246,107	0	0
2006	6	1,908,582	0	0	0	0	0	0
2007	9	976,777	2	351,367	3	1,098,108	0	0
2008	10	1,265,593	11	1,144,523	6	754,753	0	0
2009	14	1,617,232	6	563,065	0	0	1	127,909
2010	9	579,579	9	1,284,598	1	20,145	2	183,427
2011	9	593,472	16	2,683,270	5	187,410	4	466,479
2012	8	799,549	14	2,353,169	11	440,559	21	2,700,362

[a] *Source*: NDRC.
[b] *Source*: ⟨http://cdm.unfccc.int/⟩.

had been issued CERs, with the total CERs having reached 1,198,058,628 tonnes CO_2e. China possessed 733,211,880 tonnes CO_2e, accounting for 61.2% of the total amount issued. The number of registered CDM projects, expected CERs and issued CERs in China are all more than half of the total global amount—a significant contribution to the reduction of GHG emissions.

The CDM projects in China are divided into (1) energy saving and improving efficiency; (2) renewable energy; (3) recovery and utilisation of methane; (4) decomposition of nitrous oxide and trifluoromethane; (5) forestation and reforestation. The CDM projects approved by the National Development and Reform Commission (NDRC) primarily consist of renewable energy projects. The number of items accounted for 75.52% of the total number of projects approved by the NDRC and the estimated CERs (42 million tonnes CO_2e annually) accounted for 57.49% of the estimated total CERs. The Chinese CDM projects registered by the UNFCCC are also primarily concentrated on renewable energy projects, the majority of which are in the fields of wind power and hydropower [68]. MSW to energy can reduce the methane generated from landfills and the carbon dioxide produced by coal-fired power generation, thus having a dual effect on GHG emission reductions. Meanwhile, a large number of preferential policies concerning MSW to energy have been issued by the Chinese government. In recent years, MSW to energy in China has been gradually favoured by developed countries. Statistics of the MSW to energy CDM projects registered by the NDRC and the UNFCCC are shown in Table 5. It can be seen from Table 5 that, prior to 2009, the number of CDM projects registered and the CERs issued were primarily concentrated on landfill gas-fired power generation. Since 2009, MSW incineration power projects have been rapidly developed both in the number of project registrations and the amount of GHG emission reductions. In contrast, landfill gas-fired power projects registered by the NDRC are gradually declining, and those registered by the UNFCCC are developing at a comparatively lower rate. By 2012, the number of MSW incineration projects registered by the NDRC was two times that of landfill gas-fired power projects, and the amount of CERs is expected to be up to three times that of landfill gas-fired power projects; the number of MSW incineration projects registered by the UNFCCC is also two times that of landfill gas-fired power projects, and the amount of CERs is expected to be eight times that of landfill gas-fired power projects. With the demand for the development of a low carbon economy and the support of preferential policies by the Chinese government, MSW incineration power projects will occupy a larger proportion of the CDM market. As of January 2013, the CERs issued by UNFCCC for MSW incineration amount were 113,316 tonnes CO_2e, and those for landfill gas-fired power generation amount were 2,133,173 tonnes CO_2e. However, we believe that the CERs of MSW incineration will be considerably more than landfill gas-fired power generation in the next decade.

In short, the implementation of MSW to energy CDM projects can obtain funds and technology assistance from developed countries and will promote the advancement of MSW to energy industries in China. Meanwhile, China will play an active role in fulfilling the international covenant, reducing GHG emissions, and improving the local and global ecological environment.

4. Policies of MSW to energy in China

It is widely recognised that a reasonable and effective policy system can lay the solid foundation for the development of MSW to energy [23]. The Chinese government attaches great importance on the adoption and development of this novel renewable energy. Consequently, a series of policies have been released to promote its application, and various mid-and-long term plans have been issued to establish MSW to energy targets and industry guidelines.

4.1. Laws

On February 28, 2005, the fourteenth conference of the National People's Congress (NPC) passed the "Renewable Energy Law of the People's Republic of China", effective on January 1, 2006, which is the first and only legislation providing strong legal protection, as well as phased support, for the development of renewable energy sources. As the cornerstone of the development of renewable energy, it boosted the proportion of renewable energy in the energy structure dramatically, particularly wind and photovoltaic energy. However, some imperfections in this law gradually appeared during the expansion of wind and solar energy. In order to provide better legal protection, it was amended on December 26, 2009 and the amendments affecting seven articles took effect on April 1, 2010. Owing to the prosperity later than wind and solar energy, MSW to energy could benefit more from the amendments, which ensure its benign development and avoid analogous problems occurring during the development of wind and solar energy. There are some amendments closely related to MSW to energy that should be pointed out. Firstly, the amendments reiterate purchase obligation (grid companies should purchase all the electricity generated by the MSW to energy generating entities), but put it within the overall framework of the national plan, suggesting that MSW to energy is viewed as an integral part of the total national energy resource. The amendments also established a renewable energy development fund financed by budgetary allocations from the central government and the collection of renewable energy fees charged throughout China, in which the amounts accumulated are slated for use as

compensation to grid companies for the additional expenses they incur in purchasing renewable energy (as opposed to conventional energy), and for grid connection costs to facilitate the use of renewable energy, etc. [69]. Overall, the release of the law provides a broad path for the development of MSW to energy.

4.2. Administrative policies

Due to the advantages mentioned before, relevant Chinese government departments introduced administrative policies to support MSW incineration. According to the "National Programme on Climate Change in China" issued by the State Council on June 3, 2007, the industrialisation of MSW incineration technology is widely extended. The programme clearly encourages the construction of MSW incineration plants in areas where land is scarce and economically developed and encourages the development of domestic MSW incineration technologies, which provide supports for the large scale expansion of MSW incineration power generation in China [70]. On April 19, 2011, the State Council approved the "Opinions on Further Strengthening the Work of MSW Disposal". It emphasises that by 2015 the harmless treatment rate of MSW throughout the country should be over 80%, and the rate should approach 100% for all municipalities, provincial capitals and cities specifically designated in the state plan. In addition, by 2015, the resource utilisation ratio of MSW should be over 30%, and the rate should reach 50% for all municipalities, provincial capitals and cities specifically designated in the state plan. The report also states that China will further develop the resource utilisation of MSW, including recycling, incineration, and biological treatment, while prioritising MSW incineration technologies in densely populated areas where land resources are scarce [71]. On February 27, 2013, the State Grid established "Opinions on Promoting the Service in Distributed Power Parallel to the Grid" regulating that all of its privileges will be offered to MSW to energy [72]. These administrative policies clearly show that MSW incineration is an environmentally friendly industry supported by the Chinese government.

4.3. Price policies

When implementing a MSW to energy process, the environmental benefits should supersede the economic benefits. However, the financial security of the concerned enterprises is crucial for the benign development of MSW to energy. As a consequence, the state subsequently enacted two provisions on price subsidy, with the lasted one considered to be the most powerful policy to stimulate the growth of MSW incineration to energy.

On January 4, 2006, the "Trial Measures for Price Administration and Costs Sharing of Electricity Generated from Renewable Energy" was issued by the NDRC. It regulates that the benchmark power price of MSW incineration consists of the price of desulfurating coal-fired power in 2005 plus an additional US$ 0.043 per kWh of electricity subsidised by the government. This preferential price will be in place for fifteen years and is only applicable for projects established after 2006 and the power subsidy price for new power projects approved each year will be 2% less than those approved in the previous year after 2010. It also regulates that multi-fuel MSW incineration projects with conventional energy sources which supply more than 20% are not eligible for the power subsidy price. The implement of this trial measures promoted the development of MSW to energy successfully in a large scale [73]. However, due to the high costs of MSW incineration, many companies still make ends meet under the subsidy of US$ 0.043 per kWh. Although the regulation stipulated that the proportion of conventional energy must be not more than 20%, there is no effective method to measure the amount of fossil fuels in use. Therefore, several enterprises perpetrate a fraud, transforming MSW incineration power plants into small thermal power plants —contrary to the original intention of environmental protection. Because of this, the NDRC released the "The Improvement of Feed-in Tariff Policy of MSW Incineration Power Generation" on March 28, 2012 [74]. This directive increased the benchmark feed-in tariff for MSW incineration to US$ 0.11 per kWh of electricity, which is much higher than that for coal-fired power (US$ 0.04–0.05/kWh). The price differential is entirely paid by the government and will not be passed on to consumers. Meanwhile, to avoid the transformation of MSW incineration projects into small thermal power projects merely to acquire considerable subsidies, the new policy specifies that an equivalent of 280 kWh of electricity will be purchased at the benchmark feed-in tariff as the enterprises dispose of their per tonne allotment of MSW and that any redundant power will be purchased only at the benchmark price of coal-fired power. According to the practice, general MSW incineration facilities could generate approximately 300 kWh of electricity while combusting per tonne of MSW. The regulated equivalent powers in the new policy are slightly lower than empirical powers, which can curb the excessive addition of coal. The new policy also specifies the proportion limitation of the equivalent power energy. Firstly, if the equivalent power energy converted by MSW disposal amount is lower than 50% of actual on-grid energy, the plants will be treated as traditional power generation projects and could not get any price subsidy; secondly, if the converted power energy is higher than 50% but lower than total on-grid energy, the converted power energy will be purchased by subsidised price; thirdly, if the converted power energy is higher than actual on-grid energy, the total actual on-grid energy will be entitled to get subsidised price. Determining the upper and lower limits of converted power energy will regulate and promote the sustainable development of the MSW incineration industry in terms of avoiding some enterprises to gain price subsidy by cheating and forcing them to advance technologies. Fig. 9 compares the previous MSW incineration feed-in tariff and the benchmark feed-in tariff in 31 provinces and municipalities [33]. It is obvious that only the previous feed-in tariffs in Guangdong, Zhejiang, and Shanghai are higher than US$ 0.11/kWh and that the previous prices in other areas are lower than the benchmark price, especially in central and western provinces, such as Gansu, Ningxia, and Qinghai, with feed-in tariffs lower than US$ 0.082/kWh. Therefore, the implementation of the new policy will significantly improve the average profits for MSW incineration enterprises [36,75,76].

4.4. Tax policies

As a novel renewable energy, MSW incineration to energy is of importance to protect ecological environment and improve energy structure. However, this new energy, possessing the characteristics of high technology, great investment and poor risk resistance, etc., is lack of competitiveness compared to traditional power energy. Consequently, implementing preferential tax policies has been identified as a basic principle by the Chinese government for its development. Table 6 shows the preferential tax policies applied to MSW incineration. It was regulated in No. 198 [2001] that the value added tax (VAT) immediate refund was applicable to MSW to energy since January 1, 2001, which stimulated the progress of this industry. After that, in order to avoid vicious competition, a supplementary notice was issued regulating that VAT preferential policy could be applied only in case of the proportion of MSW in total fuels equal to or higher than 80%. Facing the environmental protection pressure, the government issued a new notice regulating emission standards apart from above terms. Comparing a, b and c, it can be seen that the requirements for plants to enjoy the

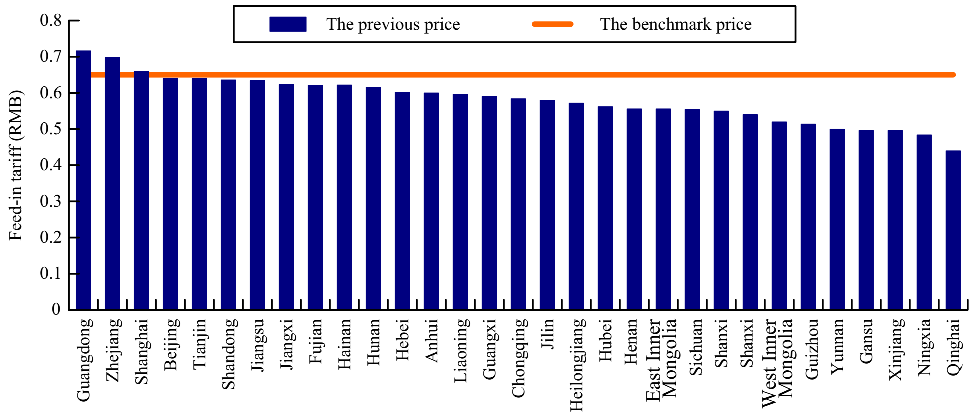


Fig. 9. The comparison of the previous and benchmark feed-in tariffs of MSW incineration. Ref. [33].

Table 6
The preferential tax policies to MSW to energy.

Tax categories	Name	Number[d]	Issued date	Concerns
Value Added Tax (VAT)	Notice on Policies regarding the Value Added Tax on Products Made through Comprehensive Utilisation of Resources and Other Products[a]	No. 198 [2001]	December 1, 2001	The VAT immediate refund is applicable to MSW to energy.
	Supplementary Notice on Policies regarding the Value Added Tax on Products Made through Comprehensive Utilisation of Resources and Other Products[b]	No. 25 [2004] of the Ministry of Finance	February 4, 2004	The proportion of MSW in the total fuels must be at least equal to or higher than 80%.
	Notice on Policies regarding the Value Added Tax on Products Made through Comprehensive Utilisation of Resources and Other Products[c]	No. 156 [2008] of the Ministry of Finance	December 9, 2008	The emissions must meet the related standards of GB13223-2003 or GB18485-2001.
Enterprise Income Tax (EIT)	Notice on Promulgation of the Catalogue for Enterprise Income Tax Preferences for Environmental Protection and Energy and Water Saving Programs (Trial)	No. 166 [2009] of the Ministry of Finance	December 31, 2009	MSW incineration plants enjoy former three-year income tax exemptions and later three-year halve.

a, b expired when coming into effect of c.
d. All the tax policies listed issued by State Administration of Taxation and Ministry of Finance of the People's Republic of China.

VAT immediate refund are increasingly higher. It is obvious that the MSW incineration industry could profit enormously from the increasingly stringent tax policies in terms of restricting unfair competition. Meanwhile, MSW incineration power generation is included in the catalogue of enterprise income tax preferential policy, which is of crucial importance to its sustainable development. These preferential tax policies demonstrate that the Chinese government holds on a powerful supportive attitude to MSW incineration.

4.5. Franchise policies

In recent years, MSW incineration power generation has grown tremendously and has become a focus of attention for international and domestic investors. MSW incineration enterprises in China have formed a mainstream business mechanism of build operate transfer (BOT) to replace the three commercial mechanism phases of direct investments by the government, management of large state-owned enterprises permitted by the government and franchise bidding by the government. At present, the MSW incineration power plants placed into operation and under construction are generally based on the mechanism of BOT. The first conference on BOT franchise of MSW incineration biding was held in Beijing on September 27, 2013, with the theme promoting and regulating the BOT franchise of MSW incineration [77].

According to the “Regulations on Franchise Management of Municipal Public Utilities” issued by the Ministry of Construction of China on March 19, 2004, the franchise of MSW management is put forward with a franchise period between 25 and 30 years [78]. Fig. 10 illustrates the process of the BOT mechanism for MSW incineration enterprises. As shown in Fig.10, the governments set up MSW to energy projects, entrust the bidding agency to initiate an open competitive bidding, and help enterprises in operating this project to get loans from the bank. The enterprises get profits from the project through preferential policies during the franchise period, and then transfer the project to the government. MSW incineration power generation projects are characterised by substantial upfront investments with relatively low operating costs. Through the mechanism of BOT, capital investments can be quickly enlarged in a short period of time, which can accelerate the pace of infrastructure construction of MSW incineration power generation and finally meet the demand for sustainable development. In addition, the levels of project management and technology will be significantly improved through the introduction of a market competition mechanism. For domestic and foreign investors, the mechanism of BOT can provide long term and stable economic benefits in an increasingly competitive market.

Because there are no set restrictions for enterprises to invest on MSW incineration projects, the competition is very fierce for newly built projects. Since the regulations, policies, standards and supervisions closely related to MSW incineration plants are increasingly stringent, the large enterprises with more capitals and higher technologies, rather than small ones, will occupy more market share. At present, 40–50 large scale MSW incineration enterprises (occupying approximately 50% of the market share in China) actively explore a practical business model of MSW incineration power generation that promotes the development of the MSW management industry in China [64]. Most of earlier

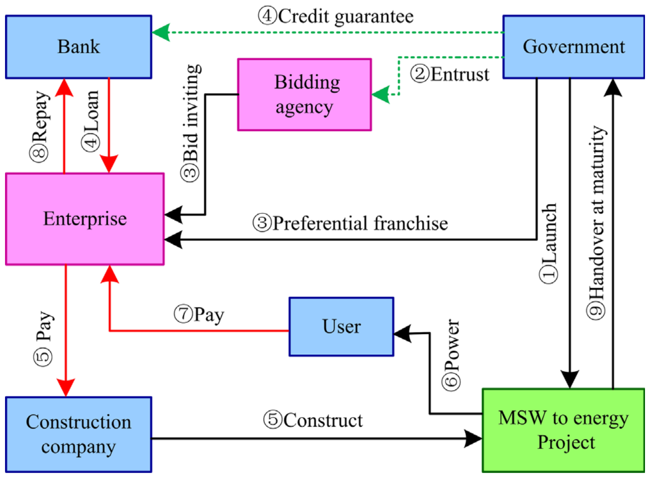


Fig. 10. The process of BOT mechanism of MSW incineration enterprises.

MSW incineration power plants constructed in China are poorly managed. In contrast, the newly built MSW incineration plants have better economic benefits due to preferential feed-in tariffs, government subsidies, and other privileges.

4.6. Plans

The "12th Five-Year Plan for National Economic and Social Development of the People's Republic of China" provides the guidance for the national economy and is the basis for all other plans. It indicates that the country should promote the resource utilisation of MSW. As one of the most effective alternatives for transforming MSW into a renewable energy resource, MSW to energy has been closely related to the national economy and social development of China [79]. In addition, MSW to energy also carries a measure of importance for China in environmental protection and has been included in various environmental protection plans. Released by the Environmental Protection Department of China on June 9, 2011, the "12th Five-Year Plan on Science and Technology for National Environmental Protection" encourages the research and development of large scale MSW incineration equipment, stoke grate technologies and process control technologies for MSW incineration [80]. The "12th Five-Year Plan for National Environmental Protection," issued by the State Council on December 15, 2011, encourages biogas generation, MSW incineration for power and heating, landfill gas-fired power generation, and resource utilisation of kitchen wastes [81].

The development of "green transformation" is extremely urgent due to severe environmental pollution in China. According to the "12th Five-Year Plan of National Energy Development" and "National Implement Program on Controlling Greenhouse Gases Emissions during the 12th Five-Year Plan", the gross national product (GNP) of carbon dioxide emissions is to decrease by 17% from 2010 levels by 2015 [6]. The Chinese government has focused attention on MSW to energy because it can significantly reduce carbon dioxide emissions. On April 29, 2012, the "12th Five-Year Construction Plan of National MSW Harmless Treatment Facilities" (hereinafter referred to as the Plan) was issued by the State Council; on December 28, 2012, the "12th Five-Year Plan of National Biomass Development" was released by the National Energy Administration; and on January 1, 2013, the State Council issued the "12th Five-Year Plan of National Energy Development." These plans all propose the following items: in Chinese cities, especially in eastern areas where there are dense populations and constrained land resources, MSW incineration power generation projects should be rationally distributed; landfill gas-fired power generation projects are suggested for adoption in the cities of western regions where landfills have been utilised; the key equipment of MSW to energy and clean-burning technologies should be vigorously boosted; it is also stipulated that the installed capacity of MSW to energy shall reach 3 million kW by 2015 [15,82,83]. Additionally, the Plan stipulates that by 2015 the MSW harmless treatment amounts in China should achieve 8.71 million tonnes daily (with cities 6.53 million tonnes daily and counties 2.18 million tonnes daily), which means that the MSW harmless disposal capacity matched with MSW production should be basically built up. The Plan also clearly states that by 2015 the MSW incineration capacity of cities and towns in China should be more than 35% of the total capacity of the MSW harmless treatment amounts, with another 48% (or more) comprised by the eastern regions.

Based on the Plan, a vast number of construction plans for MSW incineration facilities are being released by provinces and municipalities all over the country, demonstrating supportive attitudes of governments at various levels. For instance, in Guangdong Province, US$ 3.65 billion will be invested in building thirty-six MSW incineration power generation projects during the "12th Five-Year" period, adding a processing capacity of approximately 43,100 tonnes of MSW per day. During the "13th Five-Year" period, another nineteen MSW incineration power generation projects are planned to construct, adding nearly 19,500 tonnes per day of MSW processing capacity. Before 2020, MSW incineration power plants will be established in all the prefectures of Guangdong province to ensure that the proportion of MSW incineration accounts for 75% of the capacity of MSW harmless treatment [84]. For the city of Beijing, the resource utilisation rate of MSW must achieve 55% and the ratio of incineration, biological treatment and landfill will change from current 1:1:8 to 4:3:3 by 2015, regulated by the "12th Five-Year Plan of Beijing". A host of other provinces, municipalities and autonomous regions also have already planned their goals of MSW to energy, such as Liaoning, Shanxi, Jiangxi province and Tianjin, to name a few. Even though the goals are different due to the different districts, the common connotations—all levels of governments trying their best to provide financial and tax assistances as well as supervision over MSW incineration—are identical.

Through a series of policies, the preferential benchmark feed-in tariff of MSW incineration is explicitly regulated and the amount of power generation is intensively issued, showing that China maintains a strong supportive attitude towards MSW to energy—particularly in MSW incineration power generation. More importantly, the policies have effectively stimulated the MSW incineration industry and their effects will continue to be more evident in the coming years.

5. Market potential of MSW incineration in China

With further advances in technology, MSW to energy, as well as wind power, tidal power and solar power, has become novel renewable energy resources. Support for the MSW to energy industry in China will continue to grow. China has long suffered from a large population and a lack of energy resources, but once waste can readily be used an energy resource the population will gain quantifiable advantages. The average annual growth rate of MSW is 8.42% worldwide, but over 10% in China. While there are approximately 490 million tonnes of MSW generated annually in the world, China accounts for more than 150 million tonnes—over 30% of the global total [29,85]. Due to the low rate of MSW to energy in China (less than 10%), the equivalent of 2800 MW electricity is being wasted annually. This "hidden treasure" of discarded renewable energy could be as high as US$ 4.1 billion; after the full utilisation of MSW to energy, the generated economic benefits could be as high as US$ 41 billion [75,86].

The population density in many areas in China is much higher than that in developed countries such as Germany and Japan. For

instance, the population density of Jiangsu province is two times that of Japan and three times that of Germany [87]. In many cities, land resources are very valuable and the selection of a sanitary landfill site will be extremely difficult. Therefore, MSW incineration power generation, which occupies less area and substantially reduces MSW, becomes the inevitable solution in the disposal of MSW. Because novel energy utilisation technologies have been encouraged by the state, the investment on MSW incineration power generation has grown annually under the guidance of national preferential policies. According to the Plan, during the "12th Five-Year" period, the total amount of construction investment in harmless treatment facilities of MSW in China will reach US$ 43.2 billion, 4.7 times that of US$ 9.2 billion during the "11th Five-Year" period. The top three provinces or direct-controlled municipality of greatest investment are Guangdong, Shandong and Beijing, with the amount of US$ 44.5 billion, 32.6 billion and 24.0 billion respectively. The capacity of MSW incineration in China will increase from 89,625 tonnes of MSW per day during the "11th Five-Year" period to 307,155 tonnes of MSW per day during the "12th Five-Year "period, with the compound annual growth rate being 27.94% [82]. It is estimated that the overall investment on MSW incineration will be up to 87–108.8 billion dollars under the condition that the investment on MSW disposal per tonne daily is 0.4–0.5 million dollars [88]. The Plan also states that local governments should introduce incentive policies to let social funds involving in MSW incineration and encourage MSW incineration enterprises to apply for loans or grants from banks, foreign governments or financial organisations. In addition, BOT has become the preferred operation mechanism of most MSW incineration enterprises in China. The added income from power generation and government subsidies for the disposal of MSW is driving the rapid development of MSW incineration power generation projects, and the franchise period over 20 years could guarantee the long-term profits of MSW incineration plants. Therefore, it is not difficult to explain the reason why MSW incineration projects, despite average investment on a project usually over US$ 49.2 million, are becoming hot issues in environmental protection area. For example, Sound Environmental Resources Co., Ltd. has invested over US$ 240 million on MSW incineration projects merely in 2013 and Asian Development Bank will provide US$ 200 million loans to it to build MSW incineration projects [89]. At present, the financial situations of some districts in China are not optimistic in terms of revenue decrease from land sales, risks of local government bonds and shortage of construction funds for security housing, which also provides more opportunities for enterprises with sufficient funds and abundant technologies to enter this emerging industry.

Environmental protection and energy requirement as inner reasons, high population density and development of economy as external causes and various preferential policies as powerful impetus, we believe that MSW incineration power generation in China has enormous market potential. Statistics show that domestic demand for MSW incineration power generation equipment will reach US$ 5 billion over the next five years [90]. The requirements of advanced MSW incineration technologies, in addition to the necessary equipment and services for the progress of MSW to energy industries in China, will provide exciting opportunities for investors all over the world.

6. Conclusions and recommendations

An ever-increasing amount of MSW has become one of the obstacles hindering the urbanisation of China. As the inevitable choice of MSW management in China, not only can MSW to energy solve the "waste siege" phenomenon, but it also contributes to the reduction to GHG emissions. The Chinese government has implemented policies and regulations to support the application and popularisation of MSW to energy in China with early remarkable success. It should be noted that since 2012, the application of benchmark feed-in tariff policies and the strategic goals of MSW to energy established by the Chinese government have promoted progress in the industry. MSW to energy, particularly MSW incineration power generation, is destined to be prosperous and certain to have tremendous market potential in the coming decade.

However, there are still many problems with MSW to energy in China. For example, domestic MSW incineration power generation technologies have yet to be advanced, the MSW separation and recovery system need to be enhanced, and the costs of MSW incineration must be decreased. To ensure the sustainable development of MSW to energy, the following measures are strongly recommended:

1. Develop domestic MSW incineration power generation technologies suitable for the characteristics of MSW in China. Due to differences in living standards and habits, MSW in China is characterised by high moisture, low calorific value, and lack of classification compared with developed countries. MSW incineration technologies in developed countries have poor adaptability in China, leading to low efficiency in power generation and high amounts of secondary pollutants. To ensure the sustainable development of MSW incineration power generation in China, it is necessary to develop advanced MSW incineration technologies suitable for domestic MSW characteristics, especially in incinerator technologies.
2. Accelerate the process of marketisation. MSW incineration power generation is experiencing aggressive growth in China. However, the management of MSW has not yet realised marketisation in many domains. Specifically, there has been little attention paid to the source reductions of MSW, transportation, recycling, etc. It is important to learn from the experience of developed countries in matters such as the scientific classification and recycling of MSW, reasonable MSW disposal fee systems, and stringent standards to accelerate the process of MSW management in China.
3. Strengthen the classification and recycling of MSW. The scientific classification of MSW can significantly improve the efficiency of MSW to energy. To facilitate the separation and recycling of MSW, numerous MSW containers with recyclable and non-recyclable signs have been placed in residential and commercial regions in China. However, because of insufficient public outreach, most residents cannot distinguish whether items are recyclable or non-recyclable and still randomly discard waste. The government should strengthen propaganda and education on this relative knowledge. In addition, relevant regulations and appropriate proposals should be promoted to supervise residential waste disposal.
4. Perfect the relevant standards of MSW to energy. Although the Chinese government has developed numerous standards on MSW to energy, including site selections of MSW power plants, emission limits of pollutants, and equipment and technologies, there are still relatively large gaps compared with developed countries. Certain indicators are irrational and should be gradually correct with the advancement of MSW to energy technologies in China.

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